3. Water supply

- irrigation, drinking water, industrial use
- minimum discharge kept for navigation, recreation, and aquatic species

Gross use: total amount required for some purpose
Consumptive use: amount that becomes unavailable for further use
   e.g. generation of hydroelectric power demands a large gross use, but little consumptive use

Average annual discharge

For large drainage basins,
   Precipitation - Evapotranspiration = Basin discharge
If the climate is homogeneous, discharge is roughly proportional to the size of the drainage basin.
Example:

Sheep River at Black Diamond
Drainage Area  = 595 km²

\[ 595 \times 10^6 \text{ m}^2 \]

From the hydrologic atlas,
mean annual runoff =

Expected annual discharge =

In 1969-1997, the mean discharge measured at Black Diamond gauging station was 4.94 m³/s.

Mean discharge may not provide sufficient information for water supply planning, because the discharge varies significantly from one year to another.

Dry and wet periods alternate. … persistence
River and lake water levels are strongly affected by the persistence (e.g. multi-year drought).
Frequency of occurrence of small discharge
Water supply critically depends on the duration and the frequency of dry periods.

Brief review of frequency analysis

Normal distribution

Mean $\mu = 10$

$SD \sigma = 1$
Normal plot

In many cases, probability distribution of stream discharge can be approximated by the normal distribution. The table shows the annual discharge in Sheep River at Black Diamond.

To construct a normal plot;

(1) rank the data; \( m = 1, 2 \ldots n \)

(2) calculate the probability of the discharge being smaller than the given value.
\[
P = m/(n+1)
\]

(3) plot them on a normal graph paper

(4) if the plots are not on a straight line, transform the data.
\[
y = \log(x), \ y = x^2, \text{ etc.}
\]

(5) on the normal plot, estimate the values for 10%, 25%, etc.

(6) return period
\[
T = 1/P = (n+1)/m
\]

\( T \) has a unit of year, if the data set is an annual series.
Timing of runoff
Seasonal variation of flow is very important. Monthly probability diagram is useful for planning.

To construct a monthly probability diagram;
(1) Obtain a long-term record of stream discharge. e.g. Historical Streamflow Summary, Inland Waters Directorate, Environment Canada.
(2) For each month, rank the data and plot them on a probability paper.
(3) If the data do not appear as a straight line, apply a suitable transformation and plot them again.
(4) Estimate the values for 10%, 25%, etc.
(5) Plot them on a monthly probability diagram.
Flow duration curve

The proportion of the time that discharge is less than the specified value.

The flow rate in Maaragua R. is less than 0.8 cfs/mile\(^2\), 10% of time. This does not mean 36 days of each year.

Units: 1 cfs (cubic foot per second) = 0.0283 m\(^3\)/s

1 mile\(^2\) = 2.59 \(\times\) 10\(^6\) m\(^2\)

The data is expressed on a per mile\(^2\) basis because we want to compare the discharge characteristics of two drainage basins having different sizes.

- climate
- geology
Low-flow prediction

The frequency and duration of low flow periods are important factors for conservation of aquatic ecosystem.

Suppose, we want to get 0.2 cfs of water from the river for municipal water supply. Suppose also that aquatic species cannot survive if the flow below 0.2 cfs persists longer than 14 days. From the graph, we can see that the recurrence interval of such a condition is about 3 years.

Planners must weigh the risk and economic benefit of this water supply project.
Flow regulation

If dry-weather flow is much smaller than the required supply, a reservoir must be built to store water. Mass curve analysis is used to determine the reservoir capacity.

Regional water supply requires $80 \times 10^6$ m$^3$ per year. Analysis is conducted for the run of two extremely dry years in the record.

1. Pick the “shoulder” of the mass curve. The reservoir is full at this point.
2. Plot a straight line having a slope of $80 \times 10^6$ m$^3$/yr. The water is extracted from the storage in the reservoir.
3. Estimate the maximum deficit. Past this point, the flow rate exceeds the rate of extraction and the reservoir starts filling again.
Analyzing the mass curve for a long time period, we can estimate the percent of years in which the demand exceeds the reservoir capacity.

![Graph showing the required reservoir storage vs. percent of years in which the storage needed to meet the desired demand would exceed the indicated values.]

If a reservoir with a storage capacity of 30 million cubic meters were used, it would be inadequate in 28 out of every 100 years.

Probability analysis of annual storage requirements for the Perkerra River (D&L, Fig. 12-13).

**Design of small water-supply systems**

1. Estimate the demand.
   e.g. 400 L per person per day; 10,000 population
2. Estimate the minimum flow rate in the river required for navigation, recreation, aquatic ecosystem, etc.
3. Analyze the frequency and duration of low-flow periods. Is a storage facility required?
4. If a reservoir is required, analyze the mass curve and determine the capacity of the reservoir.

Note that practical design of water supply system is much more complicated.
The City of Calgary Water Supply

Two sources: Glenmore and Bearspaw Reservoirs


To optimize the water use, it is important to reduce the leakage from distribution systems.

Source: The City of Calgary, Water Works Division
Maximum water use occurs in summer. The reduction in average per-capita water use reflects the reduction in leakage.

Major increase in summer water use is caused by residential irrigation. For example, this table shows the breakdown of water use on the maximum day, July 10, 1985.

<table>
<thead>
<tr>
<th>Type of Use</th>
<th>$10^6$ L</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Irrigation</td>
<td>511</td>
<td>49</td>
</tr>
<tr>
<td>Other Irrigation</td>
<td>94</td>
<td>9</td>
</tr>
<tr>
<td>Residential Indoors</td>
<td>169</td>
<td>16</td>
</tr>
<tr>
<td>Commercial</td>
<td>62</td>
<td>6</td>
</tr>
<tr>
<td>Industrial</td>
<td>79</td>
<td>8</td>
</tr>
<tr>
<td>Leakage</td>
<td>122</td>
<td>12</td>
</tr>
<tr>
<td>Other (outside Calgary)</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>1049</td>
<td>100</td>
</tr>
</tbody>
</table>

Akuoko-Asibey (1990)